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Metacognition and the Utility of Pathway Maps in Introductory Chemistry

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HONORS PROJECT

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Introduction

General chemistry is a course that causes trouble for many individuals. Students struggle to pass the course and understand the concepts that are being taught to them. Since chemistry is a prerequisite for students majoring in the sciences, engineering, or in health professions like nursing or pre-med, the low pass rate is a significant barrier for those wishing to pursue these careers (Lewis et. al., 2009). Because of this barrier and the low passing rates of the course, many attempts have been made to find a method of teaching or learning that will increase student success and understanding. Most of these methods focus on increasing a student's ability to problem solve. Students struggle to consistently answer problems on homework and exams. Most of these homework and exam problems can be solved by memorizing an algorithm, or a set of steps that can be used to solve similar problems. However, these strategies are not effective at increasing understanding, longer-term retention of content knowledge, or problem solving. Success in problem solving is achieved when a student can break down a problem and use tactics to figure out a pathway to the correct answer (Selvaratnam and Canagaratna, 2008). The success of students in general chemistry, as well as in other courses, is dependent on their content knowledge and their ability to think critically about that set of knowledge and the question presented. Experts in a field are different from novices because they have a large expanse of connected information to use to solve problems while novices only have lists of facts that they have memorized with little to no connections between facts (Lopez et. al., 2009). The goal then is to increase success by creating more of these connections.

Many methods have been suggested for how to increase student success, some of which focus on the goal of increasing connection between knowledge. Student confidence, or the belief that they have the tools and ability to complete the problems given to them, has been linked to increased success (Taasoobshirazi and Glynn, 2009). Practice of the types of problems that will show up on an exam can increase student confidence in completing similar types of questions. Students can also be encouraged to create a representative model of the problem, like a figure or equations, which explain what is occurring in the problem so that it is easier to solve (Bodner and Domin, 2000). The ability to create these models shows that the student understands the concepts behind the problem and helps them to solve it (Sutherland, 2002). Unfortunately, if the model made for the problem is incorrect, this could lead the student to conclude the wrong answer. Another method that has been suggested to increase understanding of concepts and problem recognition involves the student being given a problem that they must develop a strategy to answer, solve the problem while writing out the concepts used to solve it, and then change to original problem into a new problem using similar concepts and solving the new problem. They are then asked to discuss who the problems relate (Siburt et. al., 2011). This helps them determine how to solve this problem, determine what concepts are being used which makes connections, and helps with problem recognition when they come across similar problems on homework and exams. Concept maps are also a method of increasing connections between concepts which can help students grow their conceptual understanding (Lyle and Robinson, 2001). This growth in understanding can raise student performance on both conceptual and algorithmic problems (Surif et. al., 2014). One other method that has been suggested to help students succeed is a method that focusses on the pathway through the problem. This method involves stating the objective, the given information, the pathway, and the answer including all concepts needed to get from given information to the answer (McCalla, 2003). One similar method encouraged students to draw out a map of the sequence of steps necessary to solve the problem being asked, including laws and principles that were needed along the way to go from one step to the next (Selvaratnam and

Canagaratna, 2008). This connects the problem with the concepts necessary to solve it and allows the students to make necessary connections.

Two major types of questions exist in general chemistry courses. These include the algorithmic problem and the conceptual problem and the performance on each type of problem varies based on student understanding (Salta and Tzougraki, 2010). Conceptual problems rely completely on the conceptual knowledge of the student. Algorithmic problems can be done by memorizing a set of steps for doing the problem and does not always require conceptual knowledge but an increase in conceptual understanding can help and student figure out the necessary steps to complete the problem (Salta and Tzougraki, 2010).

In this experiment we incorporated these ideas to test a method that we believed would help increase student understanding and performance. This method involves many of the ideas above including making connections between concepts, breaking down a problem, determining a pathway through the problem, problem recognition, and metacognition/reflection. This method, a pathway map method, involves filling out a step by step map of how a given problem was solved which includes all steps and the concepts needed to get from each step to the next. A series of pre- and post-assignments were utilized to present a problem and test for improvement in similar problems after the pathway map was completed.

Methods

The Fall 2017 Bowling Green State University CHEM 1270 class was the population used to complete this experiment. At the beginning of the semester, an email was sent out to all the students in the course, letting them know that they would take part in the experiment and giving them an overview of what it would entail. A survey was sent out that was designed to gauge what the students knew about both general chemistry course, CHEM 1250 and 1270. The survey presented them with common questions found in each class and gave them three options to choose based on the question which included: a) I am confident I can answer the question sufficiently well for graded test purposes, b) I could answer 50% of the question now and/or I know precisely where to quickly find the information to complete the answer for graded test purposes, or c) I am not confident that I could answer the question for graded test purposes. This same survey was then completed at the end of the semester to determine if there was a change in their perceived knowledge of the two courses. Additionally, the second survey asked them questions about the methods that were used during the experiment and whether they thought these methods were helpful or increased their understanding.

The experimental population was given a pre-assignment which contained one quantitative problem worth three points, followed by three multiple-choice concept questions related to the quantitative problem and worth one point each. This assignment was released on the Monday of a given week and the students were given until Wednesday, the day before recitation, to complete the assignment. During recitation which occurred on Thursday, the students filled out a pathway map which was given to them with letters that represented concepts or words given to them in a word bank. This map was based on the quantitative problem in the pre-assignment and was intended to be a tool to help them think through the steps used to solve the quantitative problem. The students filled them out in small groups while in recitation and then gave the finished maps to the professor. The next Monday, the post-assignment was assigned on Canvas and contained a very similar quantitative problem and three new multiple-choice concept questions related to the quantitative problem. This assignment was due the Thursday of that week. Examples of the pre-assignment, pathway map, and post-assignment can be found in Appendix A. Initially there were five replicates, or five different sets of assignments which covered the topics of Solutions/Colligative Properties, Kinetics, Equilibrium, Titrations, and Buffers. Unfortunately, due to time constraints and miscommunications which will be discussed later, only two replicates were completed which corresponded to the Solutions/Colligative Properties and Equilibrium assignments.

Once the replicates were completed, the pathway maps were recorded, and the student identifiers were marked as having completed or not completed the map. Those who completed the maps were used as the experimental group and those who had not were used as the control. Randomly assigned experimental and control groups were not utilized as all students were given the opportunity to complete the assignments. The pre-assignments and post-assignments were taken from Canvas and graded by hand. The quantitative problem was given more weight in the grading than the conceptual problems. The total score could range from 0 – 6, and the scores on individual sections, quantitative (0 – 3) and conceptual (0 – 3), were also recorded and used for analysis. The difference between the post- and pre-assignments was calculated by taking post-assignment score minus the pre-assignment score for the total, quantitative, and conceptual scores. This meant that a positive number signified improvement and a negative number meant regression. These differences were then combined with whether or not the student had completed the pathway map, meaning they were in the experimental group, or had not completed the pathway map, meaning they were in the control group. ANOVA was used to determine if the groups were statistically different from each other.

Results

For the first replicate, the Solutions/Colligative Properties assignment, 94 students completed both the pre-assignment and post-assignment. Of these 94 students, 69 completed the pathway maps, and thus were placed in the experimental group for this replicate, and 25 did not complete the pathway map, and thus were placed in the control group for this replicate. The students' performance on the pre-assignment was subtracted from the post-assignment to determine the difference in performance, with positive numbers meaning the students improved. Overall, on this replicate, the students did worse on the post-assignment than the pre-assignment for both the quantitative and the multiple-choice portions. The mean of these differences for each group and portion of the assignment can be seen in Table 1 below. Also in Table 1, the experimental and control group are compared using ANOVA. The F ratio comparing the mean difference of each group is listed as well as the probability of having an F that is as extreme or more extreme than the F that was calculated. If this probability is lower than 0.05, then the groups are significantly different. For this replicate, the groups were not significantly different, meaning that the pathway map process had no measurable effect on the experimental group as compared to the control group.

Table 1. Statistical data for the Solutions/Colligative Properties assignment including separation of quantitative and multiple-choice questions.

Data Set	Group	Size	Mean	Standard Error	F Ratio	Probability > F
Solutions Quantitative Portion	Experimental	69	-0.65217	0.18128	0.7669	0.3835
	Control	25	-0.96000	0.30117		
Solutions Multiple Choice Portion	Experimental	69	-0.23188	0.10354	0.4072	0.5250
	Control	25	-0.36000	0.17201		
Solutions Overall	Experimental	69	-0.8841	0.38646	0.9340	0.3363
	Control	25	-1.3200	0.23262		

The second replicate, which corresponded to the Equilibrium assignment, was completed by 106 students. The experimental group was made up of 68 students who completed the pathway map in recitation, with the other 38 students not completing the pathway map and thus being placed in the control group for this replicate. The mean difference for the assignments overall and for the quantitative portion was positive, meaning students did better on the post-assignment than the pre-assignment. Again, as with the last replicate, there was no significant difference between the control group and the experimental group indicating that the pathway map had no significant impact on student performance. The mean differences for each portion of the assignment and the statistical data can be seen below in Table 2.

Table 2. Statistical data for the Equilibrium assignment including separation of quantitative and multiple-choice questions.

Data Set	Group	Size	Mean	Standard Error	F Ratio	Probability > F
Equilibrium Quantitative Portion	Experimental	68	0.110294	0.21615	1.0133	0.3165
	Control	38	0.473684	0.28914		
Equilibrium Multiple Choice Portion	Experimental	68	-0.05882	0.09314	0.0020	0.9644
	Control	38	-0.06579	0.12459		
Equilibrium Overall	Experimental	68	0.051471	0.23363	0.8344	0.3631
	Control	38	0.407895	0.31252		

A survey was also given as a part of this experiment. The survey was given twice throughout the semester. The initial survey had 69 respondents and the final survey had 19 respondents. The first question asked what grade the students had received in CHEM 1250 which is the first semester in the General Chemistry sequence. The results of this question can be seen below in Figure 1, where the initial survey is shown in green and the final survey is shown in blue.

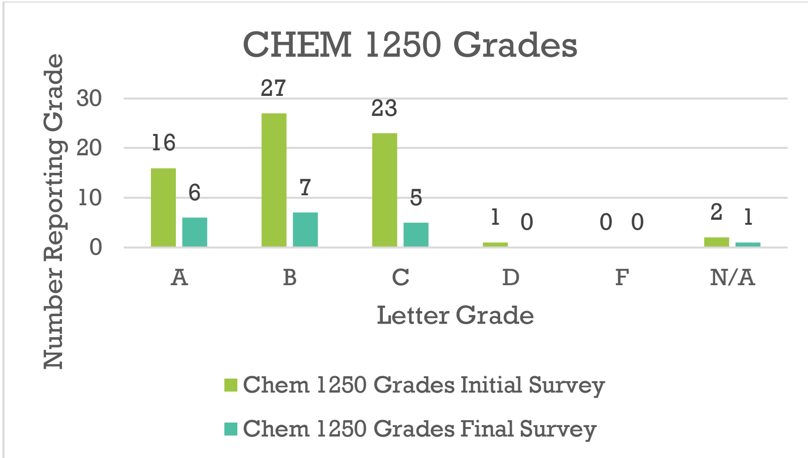

Figure 1. Self-reported CHEM 1250 grades for the CHEM 1270 students at the beginning and end of the semester. The initial survey had 69 respondents and the final survey had 19 respondents on this question.

As could be expected, most of the students reported a grade of C or higher which is required to move on to the second course CHEM 1270. The same question was asked about the students' grade for CHEM 1270, General Chemistry II, but because they had yet to complete the course, they were asked what grade they expected to receive in the course. Some of those who began the initial survey did not answer this question so the total number of respondents for the initial survey for this question fell to 67, with the final survey still having 19 respondents for this question. The data gathered from the initial and final survey can be seen in Figure 2 below, with the initial survey in green and final survey in blue. The majority of students expected a passing grade in the course although the number of C's increased while the number of B's decreased from the beginning to the end of the semester.

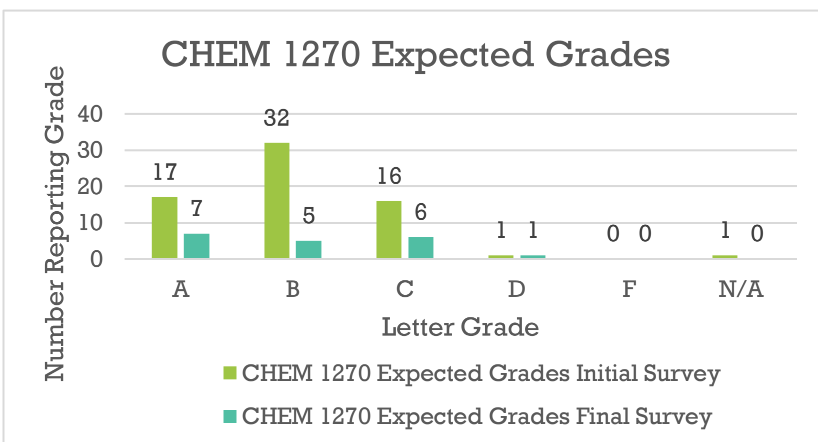

Figure 2. Self-reported CHEM 1270 grades for the CHEM 1270 students at the beginning and end of the semester. The initial survey had 67 respondents and the final survey had 19 respondents on this question.

The main portion of the survey asked the students to rank their confidence in answering questions from a range of topics that show up in general chemistry that they would encounter. This part of the survey was separated into topics they would come across in CHEM 1250, which they had taken previously, and CHEM 1270, in which they were currently enrolled. The initial survey was used to determine what their base knowledge of the content was and could then be compared to the final survey which was taken at the completion of both courses. The CHEM 1250 section contained 33 questions and the CHEM 1270 section contained 21 questions. The students were given the options of "I am confident in my ability to answer this question", "I could answer 50% of the question now", and "I cannot answer this question". In Figure 3, student responses for the CHEM 1250 portion are given, with the bars representing the percentage each of the three answers was given. The initial survey is represented in green and the final survey is represented in blue.

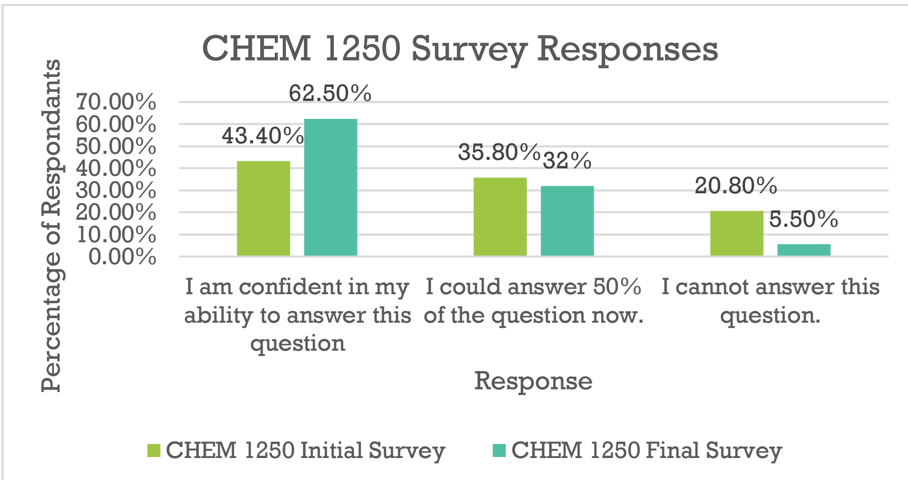

Figure 3. Student responses for the portion of the survey that tested knowledge of CHEM 1250 topics based on their confidence in answering common questions that would be asked in CHEM 1250.

There was a significant increase in the percentage of students answering that they were confident in their answers from the initial survey to the final survey and a corresponding decrease in the percentage of students who did not believe they could answer the questions. This could have been the result of a slight skew in the students who answered the survey or a general increase in knowledge from increased use of General Chemistry I techniques in the second semester course. Figure 4, shows the student responses for the CHEM 1270 portion of the survey, also represented as a percentage of total responses with green representing the initial survey and blue representing the final survey.

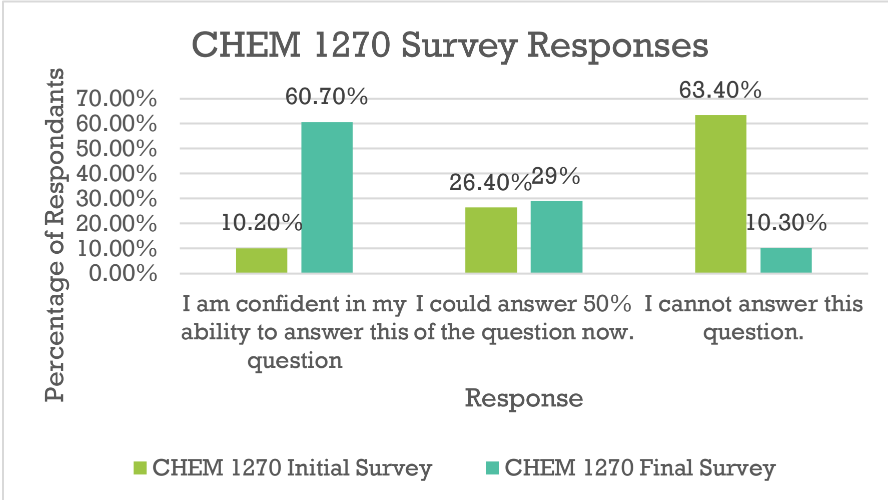

Figure 4. Student responses for the portion of the survey that tested knowledge of CHEM 1270 topics based on their confidence in answering common questions that would be asked in CHEM 1270.

Figure 4 shows that students initially were not confident in the topics for CHEM 1270 which is not surprising considering they had not learned these topics yet. The students' confidence in the topics increased dramatically from initial survey to final survey with the ability of students to confidently answer the topic questions increasing from 10.2% to 60.7% and the inability of the students to answer the questions dropping from 63.4% to 10.3%.

At the end of the final survey, the students were asked a series of questions about what they thought about the pathway map method that was used in this experiment and whether or not they believed it was helpful to them as a study method. These questions were asked as statements and the students were given the option to reply with strongly agree, agree, neither agree nor disagree, disagree, or strongly disagree. The questions asked and the students' responses can be seen below in Table 3.

Table 3. Student opinion on the pathway map method based on seven questions given in the final survey which had 19 respondents.

Question	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
I have a study method which has helped me to succeed on examinations in the past.	26.3%	52.6%	5.3%	10.5%	5.3%
Using the pathway maps helped me make connections between in class concepts and word problems in homework and exams.	10.5%	15.8%	36.8%	10.5%	26.3%
I believe that the pathway map method increased my	5.6%	5.6%	38.9%	16.7%	33.3%

understanding of concepts learning in lecture.					
I believe that the pathway map method increased my performance on homework and exam problems.	0.0%	11.1%	22.2%	33.3%	33.3%
I believe that constructing the pathway map allowed me to decide what concepts I understood and what concepts I did not understand.	11.1%	11.1%	22.2%	27.8%	27.8%
I believe the pathway method helped my overall performance in this course.	0.0%	11.1%	33.3%	16.7%	38.9%
The pathway map method helped me reflect on what I was thinking when I was solving word problems.	5.6%	16.7%	27.8%	11.1%	38.9%

As can be seen in this table, the majority students did not believe that this method was helpful to them or their overall performance. For the most part students answered that they neither agreed nor disagreed that the method was helpful, or they answered that they disagreed, for the most part strongly, that it was helpful. This may have been just personal preference or could have been the result of some of the problems that occurred when trying to implement this experiment. Also, the majority of the students answered that they already had an established study method that had helped them to succeed in the past, so they may believe their current method was a better method for them personally than the pathway map method that was used in this experiment.

Discussion and Conclusions

The pathway map method had no effect on student performance in this study. For both replicates, the variation between the control group mean difference and the experimental group mean difference was not statistically significant with P values ranging from 0.3165 to 0.9644. This can be said for the assignments overall as well as for quantitative problems and conceptual problems which were separated in the analysis. This result could have happened for a number of reasons. First, the pathway map method may have not been helpful to the students and not have accomplished the hypothesized goals of increasing metacognition, reflection, and connections between concepts. Other things could have also contributed to this stagnant response including the series of miscommunications that occurred during the process. The students were not made aware that the pathway maps were to be based off of the first question of the pre-assignment. This meant that when they filled in the blanks on the map they were not reflecting on the process they used to solve this problem but instead just attempting to fill in the blanks in a manner that made sense to them without much context. Without this information, they could not use the maps to determine where their knowledge base lacked or to make connections between concepts needed to solve the problem. This may have lead to the results that were seen in the statistical analysis of the two replicates.

Moving onto the survey data, the students did show an increase in confidence in material for both courses, CHEM 1250 and 1270. For the CHEM 1250 course, the percentage of students who were confident in their answers increase by about 19% and the percentage of students that were not confident in their answers decreased by about 15%. For both the initial and final survey, the students had successfully completed CHEM 1250, so this change could have been caused by many things. The final survey was taken by fewer students than the initial survey so the students that completed the final survey may have been those who understood the CHEM 1250 material better that the average confidence of students in the initial survey. The students could have also reviewed material from CHEM 1250 in the second semester course or used some of the concepts from the first class in the second class which could have increased their confidence as well. There was a dramatic increase in confidence in topics related to CHEM 1270 which was to be expected as most students should not have known the subjects in this course when they took the initial survey. The students' confidence in these topics increased by 50% from the initial to the final survey and their inability to answer questions related to this course decreased by 50% from the initial to the final survey. Unfortunately, there is no way to connect this increase in confidence to the pathway map method as there is no control that was not subjected to the pathway maps included in the survey. This means this increase in confidence could have been due to many factors including the pathway maps or simply passing the course.

As mentioned earlier, the students were not informed, either verbally or in written instructions associated with the assignment, that the pathway maps were linked to the first question of the pre-assignment and thus were unaware what the objective of the map was. This would have made the maps much less useful in increasing understanding as well as frustrating to complete without full instructions. Because of this, the student response in the survey makes sense. They did not find it helpful nor did they think it increased their understanding because they way method was explained was not thorough enough to give the students an idea of what was going on.

The experiment was set up to include five replicates in order to get more accurate data from the study. Only two replicates were attained from the experiment due to a mistake in the grading of one replicate which made the post-assignment worth no credit, making the students less likely to do it, and the unfortunate mismatching of the last two replicates which gave a pathway map that did not match the pre- and post-assignments.

Most of the problems that were encountered in the implementation of this experiment were the result of miscommunication. There are steps that could be taken to prevent these problems in the future. The first would be to make sure that everyone involved with the project is completely certain about what the objectives and aims of the project are and what their roles in the project are going to be. This was a problem that came up and resulted in the issues that occurred with getting all five replicates completed. One of the people working on the project did not fully understand the objective of the experiment so the post-assignment for Kinetics was skipped and the replicates about Titrations and Buffers were mixed. Along with this communication error, communication with the students needs to be improved if this were to be repeated. The students need to be made aware both verbally and on paper that the pathway maps are a method of mapping out how the first question on the pre-assignment was solved and including all concepts needed to reach the answer. They may also need to be told what the goal of the method is and the methods it employs to increase their understanding. Telling them that it is meant to help them reflect on the process necessary to complete the problem and make connections between concepts may help them use the maps to study and encourage them to complete the exercise. One other change that could be applied for the experimenter to be present during the first replicate, so any questions related to the map can be answered to clear up confusion that may arise. This way correct instructions can also be given verbally to the students. We decided not to do this because we were afraid that a stranger being in class may affect student performance and comfort level, but it may be a valuable trade off to make to ensure that the students are well-informed.

In the future, one other change that could be made to this experiment to make it more useful to students is to have a more open-ended pathway map that is created by the students for the students' use. This may help students find the process less confusing and more fit to their needs. Rather than trying to figure out which letters to put in the boxes presented, they can draw out the exact process they use allowing for more reflection on their part.

Appendix A. Example of Materials Given to Students

Recitation Assignment: Solutions and Colligative Properties, Part I

Please answer the following questions. Show all work.

1. A glucose solution contains 55.8 g of glucose ($C_6H_{12}O_6$) in 455 mL of water. The density of water is 1.00 g/mL. Determine the freezing point and boiling point of the solution. (K_b = 0.512 °C kg/mol, K_f = -1.86 °C kg/mol)

2. Which of the following is the equation that represents molality?

    a. Moles of solute/liters of solution
    b. Moles of solute/kg solvent
    c. Moles of solute/kg solution
    d. Moles of solution/liters of solvent

3. Which of the following molecules will dissociate into ions in solution?

    I. $NaNO_3$ III. $KC_2H_3O_2$
    II. $C_{12}H_{22}O_{11}$ IV. $C_{10}H_8$

    a. I
    b. II and II
    c. II, III, and IV
    d. I and III

4. Adding a solute to a solvent has what effect on the boiling point of the solvent?

    a. The addition of the solute increases the boiling point of the solvent.
    b. The addition of the solute decreases the boiling point of the solvent.
    c. The addition of the solute has no effect on the boiling point of the solvent.

Figure 5. Pre-assignment from the Solution and Colligative Properties replicate.

Recitation Assignment: Solutions and Colligative Properties, Part 2

Create your personal identifier using the instructions below. Please remember this identifier as it will be used throughout the semester. This is the same identifier you used on the survey. {First two letters of the town you grew up in} - {Two digits representing the day of the month of your birthday} - {two digits representing the month of your mother's birthday} - {last 5 numbers of your student ID}example: CA-01-08-29910

Personal Identifier ______________________________

Please fill out the following pathway map for question 1 using the words in the term bank. Each box will have only one letter in it which represents the correct term from the term bank. The boxes above the arrow represent the concept or property needed to be used to get from the box on the left side of the arrow to the box on the right side of the arrow.

TERM BANK:

A. grams of glucose
B. grams of water
C. moles of glucose
D. moles of water
E. molar mass of glucose
F. molar mass of water
G. milliliters of glucose
H. milliliters of water
I. liters of glucose
J. liters of water
K. kilograms of glucose
L. kilograms of water
M. density of glucose
N. density of water
O. 1000 g = 1 kg

P. molarity
Q. moles of solute/ liters of solution
R. molality
S. moles of solute/ kilograms of solvent
T. $\Delta T_f = i\ m\ K_f$
U. $\Delta T_b = i\ m\ K_b$
V. ΔT_f
W. ΔT_b
X. boiling point of glucose – T_b
Y. boiling point of water – T_b
Z. freezing point of glucose – T_f
AA. freezing point of water – T_f
AB. boiling point of solution
AC. freezing point of solution

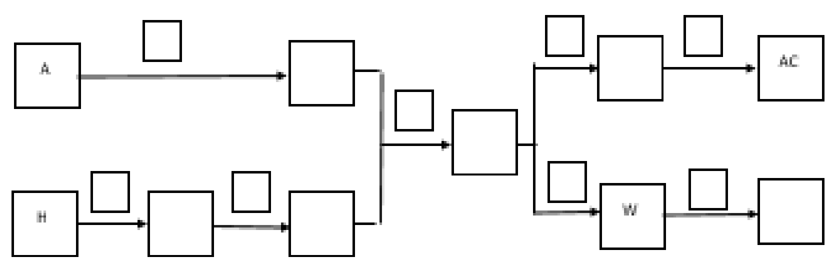

Figure 6. Pathway Map for the Solutions and Colligative Properties replicate.

Name

Recitation Assignment: Solutions and Colligative Properties, Part 3

Please answer the following questions. Show all work.

1. Calculate the freezing point and boiling point of a solution containing 10.0 g of naphthalene ($C_{10}H_8$) in 100.0 mL of benzene. Benzene has a density of 0.877 g/mL. Benzene has a freezing point of 5.5 °C and a boiling point of 80.1 °C. (K_b = 0.512 °C kg/mol, K_f = -1.86 °C kg/mol)

2. Which of the following is the equation that represents molarity?

   a. Moles of solute/liters of solution
   b. Moles of solute/kg solvent
   c. Moles of solute/kg solution
   d. Moles of solution/liters of solvent

3. Which of the following molecules will dissociate into ions in solution?

   I. C_2H_6 III. $NaC_2H_3O_2$
   II. Li_2SO_4 IV. $C_6H_{12}O_6$

   a. I
   b. II and III
   c. II, III, and IV
   d. I and III

4. Adding a solute to a solvent has what effect on the freezing point of the solvent?

   a. The addition of the solute increases the freezing point of the solvent.
   b. The addition of the solute decreases the freezing point of the solvent.
   c. The addition of the solute has no effect on the freezing point of the solvent.

Figure 7. The post-assignment for the Solutions and Colligative Properties replicate.

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